Human & Robotic Exploration

Overview of FY2002 Group 1 Revolutionary Aerospace Systems Concepts (RASC)

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Group 1: Human & Robotic Exploration

FY01-FY02 Activities

- **Human & Robotics Exploration Mission Objective:**
  - **Identify revolutionary architectures, concepts, and key technologies for Human and Robotics systems which have the potential, when synergistically combined, to reduce the time, distance and safety barriers associated with scientific exploration beyond Low Earth Orbit (LEO)**

- **Rev·o·lu·tion·ar·y adj.**
  - **. . . Characterized by or resulting in radical change.**

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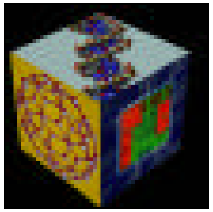
Goal Three: Pioneer Technology Innovation

NASA's goal is to enable a revolution in aerospace systems.

In order to develop the aerospace systems of the future, revolutionary approaches to system design and technology development will be necessary. Pursuing technology fields that are in their infancy today, developing the knowledge bases necessary to design radically new aerospace systems, and performing efficient, high-confidence design and development of revolutionary vehicles are challenges that face us in innovation. These challenges are intensified by the demand for safety in our highly complex aerospace systems. The goal to Pioneer Technology Innovation is unique in that it focuses on broad, crosscutting innovations critical to a number of NASA missions and to the aerospace industry in general.



Technology Innovation: Develop revolutionary technologies and technology solutions to enable fundamentally new aerospace system capabilities and missions

Objective 10: Within 10 years, integrate revolutionary tech - nologies to explore fundamentally new aerospace system capa - bilities and missions; and within 25 years, demonstrate new aerospace capabilities and new mission concepts in flight.

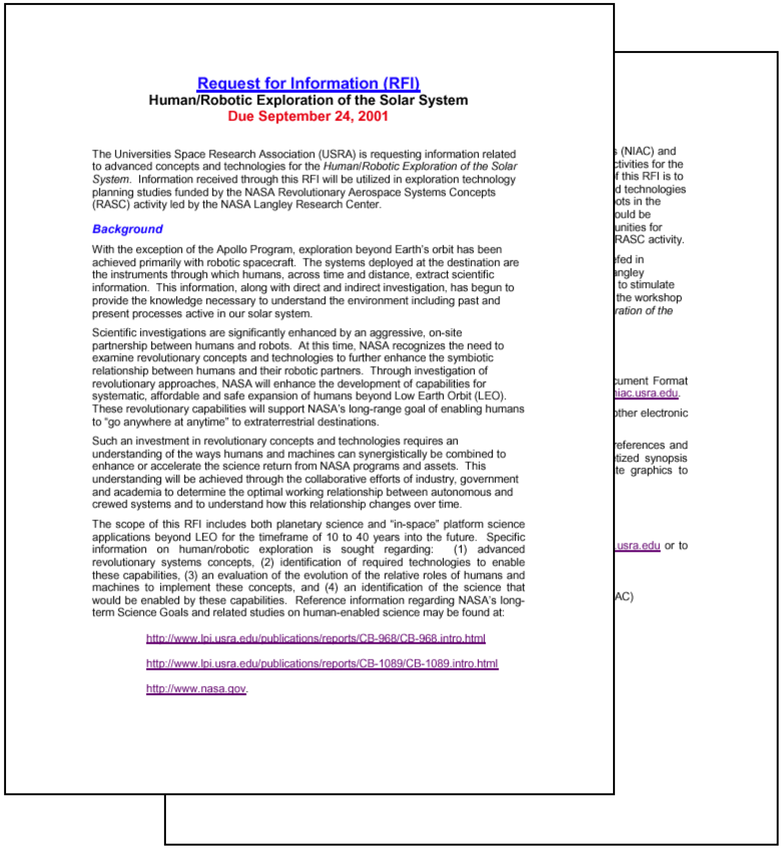
Ongoing FY2001 Study Activity

- Universities Space Research Association (USRA) Task Mission Objectives:
  - Attempt to engage a broad audience for solicitation of creative/revolutionary ideas
  - Use a collaborative effort of academic, industrial and government experts to identify potential revolutionary aerospace systems concepts for scientific exploration beyond LEO with both Humans and Robots
  - Gain an initial understanding of the revolutionary technologies associated with these Human and Robotic systems concepts which would, if developed, maximize the probability of meeting NASA's Exploration Grand Challenges

USRA Task Approach

- **Conduct a NASA-style Request for Information (RFI) through the *NASA Institute for Advanced Concepts* (NIAC) in order to solicit ideas from academic, industrial and government experts**
- **Use ongoing NASA activities associated with Human and Robotic exploration beyond LEO to establish initial mission requirements associated with planetary and in-space platform science scenarios**
- **NIAC Evaluation and compilation of RFI responses**
- **Conduct a RASC focused Human & Robotics exploration workshop to integrate expert ideas with the results of the RFI activity**

- **RFI released through the NIAC website on July 25, 2001**
  http://www.niac.usra.edu/rfi/HR_RFI.1.pdf
- **26+ Proposals received as of September 24, 2001**



Request for Information (RFI)
Human/Robotic Exploration of the Solar System
Due September 24, 2001

The Universities Space Research Association (USRA) is requesting information related to advanced concepts and technologies for the *Human/Robotic Exploration of the Solar System*. Information received through this RFI will be utilized in exploration technology planning studies funded by the NASA Revolutionary Aerospace Systems Concepts (RASC) activity led by the NASA Langley Research Center.

Background

With the exception of the Apollo Program, exploration beyond Earth's orbit has been achieved primarily with robotic spacecraft. The systems deployed at the destination are the instruments through which humans, across time and distance, extract scientific information. This information, along with direct and indirect investigation, has begun to provide the knowledge necessary to understand the environment including past and present processes active in our solar system.

Scientific investigations are significantly enhanced by an aggressive, on-site partnership between humans and robots. At this time, NASA recognizes the need to examine revolutionary concepts and technologies to further enhance the symbiotic relationship between humans and their robotic partners. Through investigation of revolutionary approaches, NASA will enhance the development of capabilities for systematic, affordable and safe expansion of humans beyond Low Earth Orbit (LEO). These revolutionary capabilities will support NASA's long-range goal of enabling humans to "go anywhere at anytime" to extraterrestrial destinations.

Such an investment in revolutionary concepts and technologies requires an understanding of the ways humans and machines can synergistically be combined to enhance or accelerate the science return from NASA programs and assets. This understanding will be achieved through the collaborative efforts of industry, government and academia to determine the optimal working relationship between autonomous and crewed systems and to understand how this relationship changes over time.

The scope of this RFI includes both planetary science and "in-space" platform science applications beyond LEO for the timeframe of 10 to 40 years into the future. Specific information on human/robotic exploration is sought regarding: (1) advanced revolutionary systems concepts, (2) identification of required technologies to enable these capabilities, (3) an evaluation of the evolution of the relative roles of humans and machines to implement these concepts, and (4) an identification of the science that would be enabled by these capabilities. Reference information regarding NASA's long-term Science Goals and related studies on human-enabled science may be found at:

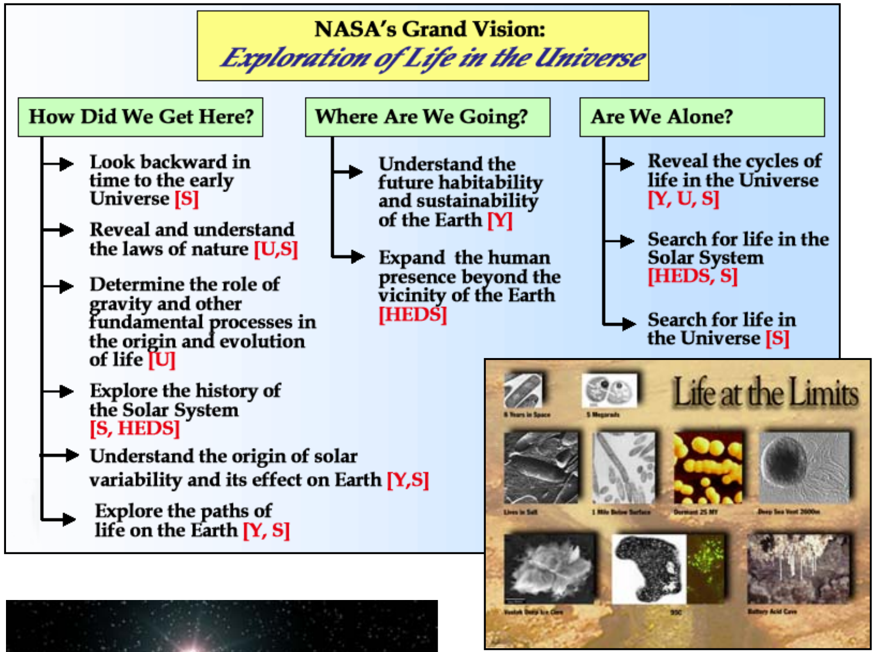
http://www.lpi.usra.edu/publications/reports/CB-968/CB-968.intro.html

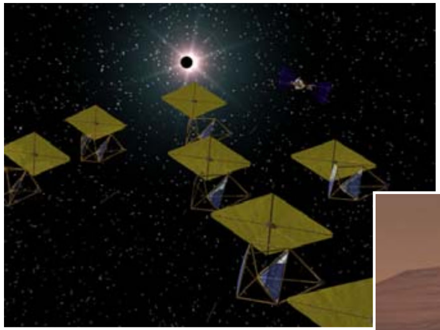
http://www.lpi.usra.edu/publications/reports/CB-1089/CB-1089.intro.html

http://www.nasa.gov.

Associated Exploration Related Activities

- USRA will coordinate their study activity with data and results from a number of ongoing Human and Robotic exploration activities in order to:
  - Ensure that the latest information on scientific exploration goals, requirements and grand strategies are employed to develop more detailed study science scenarios
  - Coordinate methodologies for assessing potential revolutionary concepts and technologies
  - Collect as many appropriate systems concepts from as diverse a population as possible to increase potential for incorporation of creative ideas





ICASE Human/Robotics Workshop near LaRC

- **ICASE/NASA LaRC Workshop on Revolutionary Aerospace Systems Concepts for Human Robotic Exploration of the Solar System scheduled for *November 6-8, 2001 in Hampton, VA***
- **Primary workshop objectives are to:**
  - **Present key results from the USRA RFI**
  - **Capture an overview of current scientific exploration goals, objectives, and top level requirements**
  - **Provide a forum for the free exchange of ideas dealing with revolutionary systems concepts and technologies associated with Human and Robotic exploration beyond LEO**
- **Workshop announcement placed on ICASE website on July 25, 2001**

  http://www.icase.edu/workshops/hress01.html
- **Initial contact with key participants initiated at the beginning of July**

ICASE ANNOUNCEMENT

ICASE/LaRC WORKSHOP ON REVOLUTIONARY AEROSPACE SYSTEMS CONCEPTS FOR HUMAN/ROBOTIC EXPLORATION OF THE SOLAR SYSTEM

November 6-7, 2001

Location: NASA Langley Research Center, Hampton, Virginia

Organizers: Josip Loncaric, Lewis Peach and Manuel D. Salas

To get added to the workshop mailing list, send e-mail to: Emily Todd

WORKSHOP OBJECTIVES

Exploration of the solar system will be most effective if both humans and robots are synergistically combined. Done correctly, this approach can reduce risks, improve efficiency and accomplish goals faster. The challenge is to understand the ways in which this could be accomplished and how this mix might evolve over the next 10-40 years with the incorporation of revolutionary aerospace systems concepts. This workshop aims to gather relevant input from industry, government and academic experts to support the development of a preliminary plan which would maximize the scientific return.

The scope of this effort includes both planetary science and "in-space" platform science applications beyond low Earth orbit. Specific objectives are: (1) advanced revolutionary systems concepts, (2) identification of required technologies to enable these capabilities, (3) an evaluation of the evolution of the relative roles of humans and machines to implement these concepts, and (4) an identification of the science that would be enabled by these capabilities.

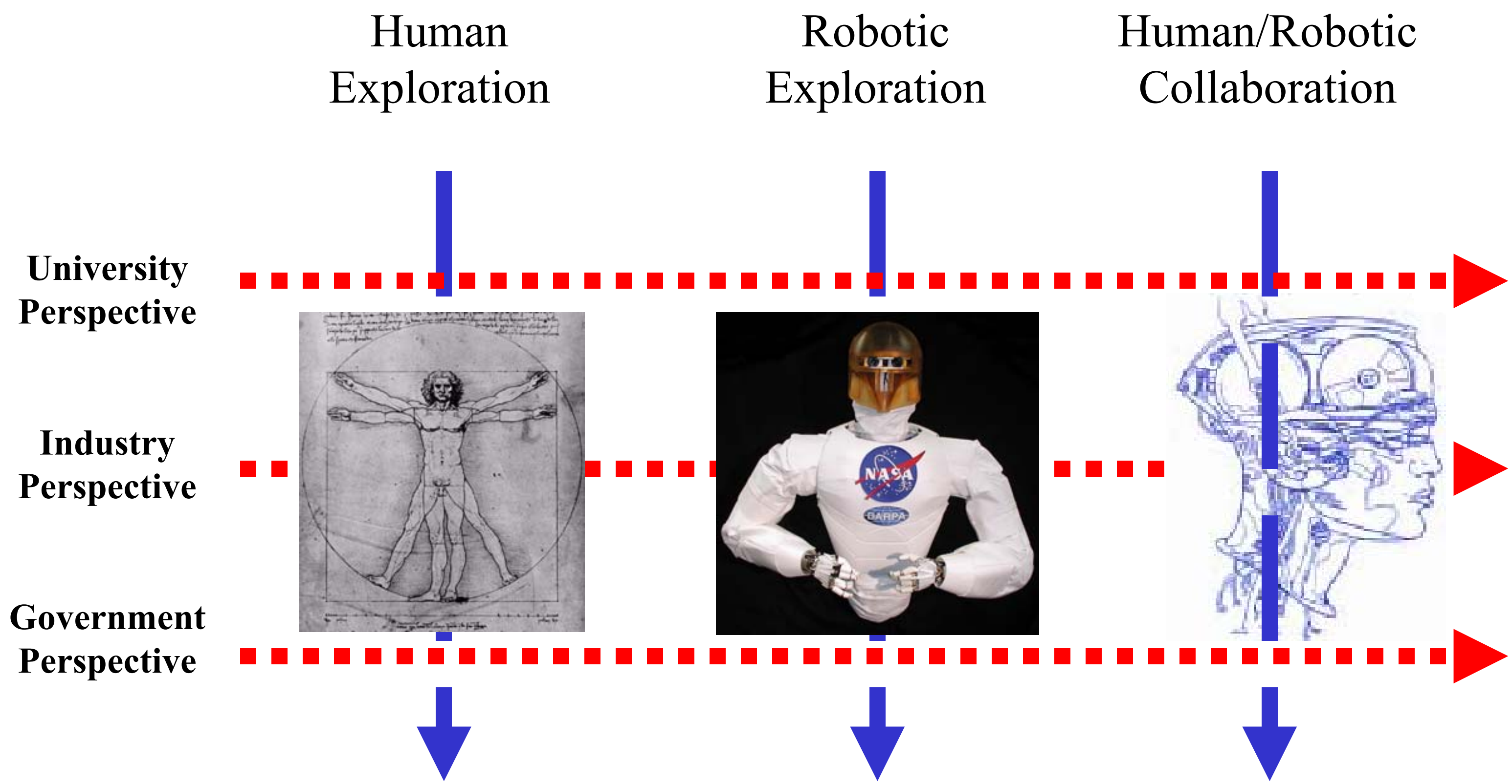
Support for this project was provided by the Revolutionary Aerospace Systems Concepts (RASC) activity at NASA Langley Research Center.

AGENDA

Tuesday, November 6, 2001:
- Invited presentations (plenary session)
- Discussions (parallel sessions: human exploration, robot exploration, enabled science)

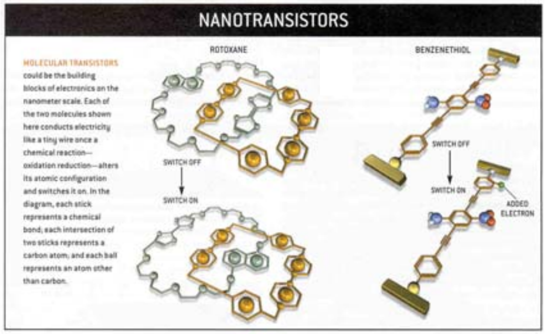
Wednesday, November 7, 2001:
- Summary of yesterday's discussions and additional presentations (plenary session)
- Discussions (parallel sessions: planetary scenarios, platform scenarios, technologies)
- Summary of today's discussions (plenary session)

Workshop Structure - Tuesday



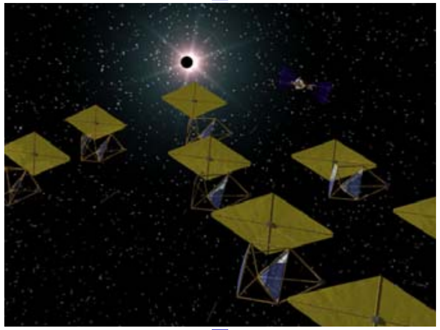
Workshop Structure - Wednesday

Revolutionary
Technology Presentations



Revolutionary Planetary
Scenarios Development

Revolutionary Platform
Scenarios Development



Planned FY 2002 Activities

- 5 Study activities are currently planned for FY2002
  - **Human/Robotic Exploration Advanced Concept Development Using Revolutionary Aerospace Systems (Cirillo/LaRC)**
    - Science exploration requirements development based on NASA Grand Challenges
    - Scenario development
    - Concept development (NASA/USRA)
    - Revolutionary Technology Identification
  - **Human and Robotic Cooperative Teams Beyond LEO (Weisbin/JPL)**
    - Focus on hybrid Human/Robotic system architectures
  - **Advanced In-Space EVA Capabilities (JSC)**
    - Focus on in-space EVA capabilities to enhance operations through improved space suit flexibility with associated technology roadmap
  - **Human Emplacement of Lunar Telescopes (LaRC)**
    - Assess effectiveness of astronomical telescopes on the Moon and their optimum design features
  - **Airborne Exploration of the Planets (Gelhausen/LaRC)**
    - Assess airborne systems concepts for the purpose of identifying the long-term technology program required to reduce concept risk and increase cost effectiveness

Robotics Research Areas (NEXT)

- **Requirements Areas needing additional research and development effort include:**
  - **Reliability**
  - **Autonomy**
  - **Robot Team Coordination**
  - **Robots for Labor**
  - **Robots for Exploration and Discovery**

Requirement/ Utilization	Functionality and Research Needs
Reliability	• Robot mechanical and computational reconfiguration and redundancy must achieve the reliability necessary for lifetimes of years, millions of cycles of operations and potentially thousands of kilometers of travel • Computer hardware and software architectures must be robust to radiation-induced upsets and must adapt to changes in system behavior resulting from electrical or mechanical damage or environmental shifts
Autonomy	• Research must imbue robots with independent reasoning which will eliminate the need for persistent oversight by humans • Future robot operators should be able to direct complex tasks with a specification of the goal and constraints • Should a robot require assistance when presented with a particularly difficult task or in an emergency, the robot operator must be able to supercede the automatic functionality, controlling the robot at the level of manipulation or locomotion
Robot Team Coordination	• Building construction and regional planetary survey are campaigns beyond the capability of any one robot. Bold agendas such as these will require teams of autonomous agents working in concert • Robot teams must be able to organize themselves to perform successfully and efficiently, despite team member heterogeneity, equipment malfunction and constantly evolving goals
Robots for Labor	• Robots will be required to construct large-scale orbiting facilities which may be kilometers in extent and composed of millions of elements; space solar power facilities are envisioned in geosynchronous orbit whose harsh radiation environment may eliminate the possibility of employing human construction crews • Software architectures and communications networks must support the coordination of robots which will walk and work together to build and maintain, where success is ensured despite occasional robot failure • Surface robots must be light enough for transportation to a planetary surface but massive enough for earth moving operations
Robots for Exploration and Discovery	• Robots will take a greater role in planetary surface exploration, both independently and alongside astronauts o Future robots will handle the repetitive or time-consuming tasks of data collection, leaving humans to handle the high-level interpretation of information o Research must drive autonomous science and discovery capabilities far beyond the current level, enabling efficient geologic and biologic surveys of vast regions • On a planning level, robots must be able to determine the path across a planetary landscape which will lead to the greatest scientific information gain, and optimize its collection and use of solar power and other resources • Interaction between humans and robots will require new interfaces, with speech and gesture recognition, which are natural for the humans and effective for scientific field use

Figure 6-14: Robotics Research Issues.

Bioastronautics/Medical Care Technology Areas (NEXT)

- Requirements Areas needing additional research and development effort include:
  - Adaptation and Countermeasures
  - Health Care Systems and Clinical Care
  - Advanced Human Support
  - Crew Performance
  - Radiation Risk and Mitigation

Technology Areas	Issues and Description of Technology Need
Adaptation and Countermeasures	• Countermeasures are necessary to maintain health and performance during flight and upon return to Earth • Adaptations to spaceflight including fluid shift which initiates cardiovascular changes, continual bone demineralization, muscular atrophy, initial neurosensory and neuromotor dysfunction during transition between different gravity environments (e.g., space motion sickness), etc. • Further technology development is needed for countermeasures involving exercise regimens, pharmacologic supplements and/or enhanced nutrition, neurosensory and neuromotor monitoring and stimulation, and exploration of artificial gravity as a multi-system countermeasure
Health Care Systems and Clinical Care	• Broader range of health care capabilities are needed as medical evacuation to Earth becomes more impractical • Modeling and simulation technologies • Inflight systems to perform in-vivo, non-invasive analysis and to process/downlink data (biosensors to monitor blood chemistry, pulmonary gases, and metabolites; telemedicine systems for orbital operations, etc.)
Advanced Human Support	• Life support and environmental monitoring o Highly reliable, self-sufficient life support systems that minimize mass, power, volume and crew time requirements o Real time, autonomous monitoring of air, water and food for microbial and chemical contamination • Crew accommodations o Exploration missions require self-sufficient and highly reliable systems and resources o Technology needs include: repair and maintenance systems without Earth support, extension of shelf life for diet needs, decision-support systems for critical event response
Crew Performance	• Human factors o Non-intrusive methods for monitoring individual/group performance over time o Autonomous means for information capture and collection o Improved user interfaces and displays • Training o Advanced computer and simulation systems o Onboard training systems for new or infrequent tasks • Psychosocial health o Continuous, integrated assessment of mental status o Means for personal communications and recreation through interactive systems o Adaptive diagnostic system
Radiation Risk and Mitigation	• Technology development is required to reduce/compensate radiation effects o Monitoring the radiation environment and dose received o Predicting changes in the radiation environment o Development radiation shielding and pharmacology • Specific technologies include: o Active, solid state, personal radiation dosimeter o Neutron dosimeter o Solar particle event (SPE) early warning system o Improved models for the radiation environment, shielding, and radiation transport o Chemical and biological modifiers and radioprotectants o Improved composite materials for radiation and hypervelocity impact shielding

Figure 6-16: Bioastronautics/Medical Care Technology Areas.

Back Up Information

Planned FY 2002 Activities (continued)

- **Human/Robotic Exploration Advanced Concept Development Using Revolutionary Aerospace Systems**
  - **Study Lead: Bill Cirillo, LaRC [Original proposal submitted by Melvin Ferebee]**
  - **Objective(s):**
    - Develop and/or compile NASA science exploration requirements based on NASA Grand Challenges for 2025 and beyond
    - Develop 2025 model of potential technologies independent of NASA needs
    - Identify potential revolutionary systems concepts to meet NASA mission requirements
    - Identify NASA mission specific needs/areas that are not addressed by outside agencies/companies/universities
    - Identify potential revolutionary technologies based on revolutionary systems concepts, RATS inputs, etc.
    - Integrate results of parallel Group 1 studies

Planned FY 2002 Activities (continued)

- **Human and Robotic Cooperative Teams Beyond LEO**
  - **Study Lead: Chuck Weisbin, JPL**
  - **Objective(s):**
    - Analyze human and robotic assets working jointly in space scenarios beyond Earth orbit
    - Potential future mission concepts include:
      - In-space assembly of complex structures, such as astronomical observatories
      - Lunar astronomical observatories & complex science facilities
      - Asteroid mining
      - Surface science exploration, such as extensive geological exploration on the Moon and Mars
    - FY02 analysis will focus on 2 mission scenarios, involving in-space structure deployment and surface science as defined in FY 01 by the multi-center (JSC/JPL/ARC/LaRC/Hq) NASA Human-Robot Joint Enterprise Working Group
      - The analysis will take these 2 conceptual scenarios as a starting point, and provide technological options in human/robot team architecture options required to enable these scenarios

Planned FY 2002 Activities (continued)

- **Human and Robotic Cooperative Teams Beyond LEO (continued)**
  - Analysis will include:
    - Determination of optimal robot and human roles in space for range of mission scenarios ?
    - Identification of those tasks for which humans and/or robots are each critical; for what mission operations are humans so critical that the benefit compensates for risk and cost.
    - Identification of mission architectures and procedures to best combine human and robot roles in first-of-kind space operations.
    - Identification of technology gaps where neither human or robot technology meets anticipated requirements.
    - Quantification and analysis of performance for various human/robot system architecture options, as determined in controlled laboratory conditions.
    - Trades of various types of mission and system architectures, e.g.,
      - » Remote tele-presence, with human at a control station and robots operating in supervisory control at a remote location
      - » Cooperative task execution, with both humans and robots operating jointly at a remote location

Planned FY 2002 Activities (continued)

- **Advanced In-Space EVA Capabilities**
  - **Study Lead: TBD, JSC [Original proposal submitted by Mary DiJoseph, HQ]**
  - **Objective(s):**
    - Develop designs for advanced EVA systems/spacesuits for highly-capable human operation in free space:
      - Undertake the development of multiple EVA system designs that achieve the goals of deploying, servicing, rescuing, repairing, and upgrading future major space facilities in free space
      - Alternative designs will be broad enough to include a range of human-enhancing capabilities: telerobotics from a station, ‘man-in-a-can’, etc
      - In all cases, optimized coordination with advanced robotics will be incorporated
    - Develop a technology investment/EVA capabilities ‘roadmap’ for the next two decades:
      - Develop a roadmap for free-space EVA that lays out an investment and development strategy and recommendations that would lead to enhanced human/robotic operation in space by the 2020+ timeframe

Planned FY 2002 Activities (continued)

- **Human Emplacement of Lunar Telescopes**
  - **Study Lead: TBD, LaRC [Original proposal submitted by Harley Thronson, HQ]**
  - **Objective(s):**
    - Assess how effectively astronomical telescopes would work on the Moon
      - Critically examine telescopes on the surface of the Moon in terms of:
        - » Environmental limitations to sensitive operation on the surface of the Moon compared to free space
        - » Technological solutions which might mitigate these limitations
        - » Identification of operational constraints for surface and free-space operation of astronomical observatories
        - » Based on the science priorities of the Office of Space Science, this study would concentrate on ultraviolet, visual, and infrared wavelengths
        - » Assess siting telescopes in unique locations, such as shadowed craters near the lunar poles, or other special situations that could use the environmental properties of the Moon in novel ways for emplacement of telescopes

Planned FY 2002 Activities (continued)

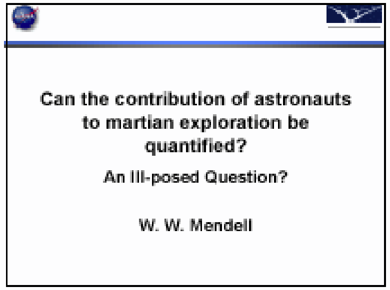
- **Human Emplacement of Lunar Telescopes (continued)**
  - Assess the optimum designs for large astronomical telescopes on the Moon's surface
    - Designs for complex scientific facilities on the Moon's surface or elsewhere are likely to depend strongly upon the techniques used for construction, repair, and servicing
    - Assess the problems of fabrication, transportation, erection, and operations of a telescope on the Moon and identify the technology capabilities needed to overcome the challenges
    - Characteristics to be considered are:
      - » Expected performance of the lunar telescope
      - » Operational concept for deploying the instrument on the Moon, optimally using humans and machines to assemble the instrument
      - » Operational concept for repairing or upgrading the instrument, including roles of humans and robots
      - » Transportation cost for moving the telescope from Earth to the Moon's surface

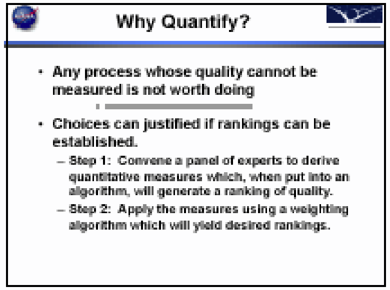
Planned FY 2002 Activities (concluded)

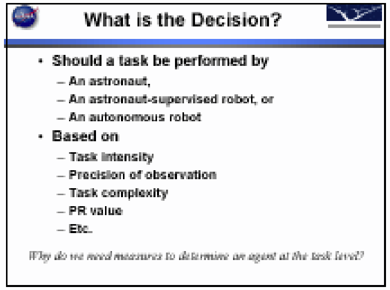
- **Airborne Exploration of the Planets**
  - **Study Lead: Paul Gelhausen, LaRC**
  - **Objective(s):**
    - Assess the airborne planetary mission concept(s) from a top down perspective for the purpose of developing the long-term technology program to make the benefit to risk ratio acceptable to the exploration community.
    - Evaluate the potential system performance and cost for a number of different concepts
    - Several different science missions would be outlined
    - Missions types would range from sampling to reconnaissance missions
    - Combined ground-air and solo missions would also be evaluated.
    - Concepts would consider the launch, space flight, entry, deployment and all phases of the planetary operation
    - Windows of opportunity and mission concepts for planets and moons that have atmospheres would be identified

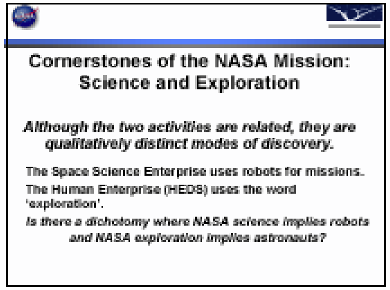
Associated Exploration Related Activities (concluded)

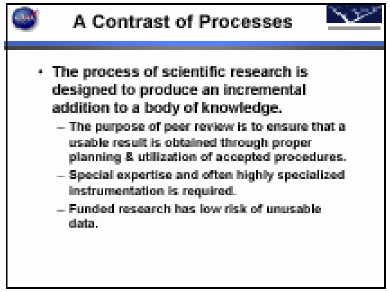
- **Related activities include:**
  - **HEDS/Martin - NASA Exploration Team (NEXT)**
    - HQ/DiJoseph - NASA Human/Robotics Working Group
    - HQ/Thronson - Exploration Science Working Group
    - RATS
  - **JPL/Weisbin - Quantitative Analysis & Assessment Methods**
  - **JSC/Cooke & USWF/Ford - Human Centered Computing Methodology**
  - **JSC/Dickerson & UT/Muehlberger - Apollo Lessons Learned**
  - **HEDS/SSE/USRA/Duke - Human Enabled Science**
  - **SSE/MEP/Garvin - Mars Exploration Program Goals & Planning**
  - **SSE/Origins/Thronson - Long-Term Platform Science Goals & Planning**
  - **SSE/Meyer - Search for Life in Extreme Environments**
  - **NIAC/Cassanova - NIAC Advanced Concepts Workshop (10/30 - 11/1)**

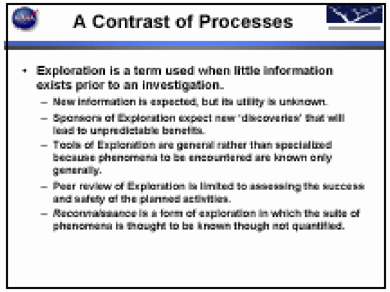












Preliminary Workshop Agenda

Tuesday, November 6

7:30 am Continental Breakfast

8:15 am Introduction

8:30 am Invited presentations on NASA goals in planetary science, platform science and in human exploration
- Mankins
- Garvin
- Thronson
- Nealson

10:30 am Break

10:45 am Invited presentations on human enabled science, robot enabled science, societal needs, and a summary of the NIAC RFI results
- Duke
- Dubowsky
- Jakosky [TBC]
- Cassanova

12:30 pm Catered buffet lunch

1:30 pm Parallel Sessions 1 - Government Perspective
[Human exploration] [Robot Exploration] [Collaboration]

2:30 pm Parallel Sessions 2 - University Perspective
[Human Exploration] [Robot Exploration] [Collaboration]

3:30 pm Break

4:00 pm Parallel Sessions 3 - Industry Perspective
[Human Exploration] [Robot Exploration] [Collaboration]

5:00 pm Adjourn for the afternoon

7:00 pm Dinner (Guest Speaker - Kerwin)

Wednesday, November 7

7:30 am Continental Breakfast

8:00 am Summaries of Tuesday's parallel sessions [Humans/Robots/Collaboration]

9:00 am Invited presentations
- Ford
- Rodriguez
- Flowers [TBC]

10:30 am Break

11:00 am Technology Session 1

12:30 pm Catered buffet lunch

1:30 pm Technology Session 2

3:00 pm Parallel Sessions
[Planetary scenarios] [Platform scenarios]

4:30 pm Summaries of today's parallel sessions and open discussions
[Planetary scenarios] [Platform scenarios]

5:00 pm Concluding remarks

5:15 pm Adjourn

Study Schedule

- **Participate in JPL/Weisbin - Performance Assessment Methodology Workshop** **(6/21/01)**
- **Obtain RASC Concurrence on Study Plan** **(6/28/01)**

- **Initial Contact with Potential Key Presenters** **(July)**
- **NIAC RFI Release Notice on NIAC Website** **(7/15/01)**

- **Invitations to ICASE Workshop** **(August)**
- **Publish NIAC RFI Notification** **(8/01/01)**

- **NIAC RFI Proposals Due** **(9/24/01)**

- **Mid-Term Report Due** **(10/1/01)**
- **NIAC RFI Peer Review, Prioritization and Recommendations Complete** **(10/30/01)**
- ***NIAC Advanced Concepts Workshop (not a formal part of RASC Study)*** ***(10/30-11/1/01)***

- **RASC/ICASE Workshop @ LaRC (8th Report writing day for Session Chairs)** **(11/6-8/01)**

- **Draft Final Report (with visuals) Development and Iteration** **(Dec-Jan)**

- **Final Report and Summary Presentation** **(01/30/02)**

Key Study Participants

• **RASC Study Manager:**	William Cirillo
• **USRA Participants:**	
– **USRA HQ:**	
• Lewis Peach	Overall Coordination
• Hussein Hussein	University Collaboration
• Michael Duke	Human Enabled Science
– **NIAC:**	
• Bob Cassanova	Mini RFI Process
– **ICASE:**	
• Manuel Salas	Overall ICASE Lead
• Josip Loncaric	RASC/ICASE Workshop
• Vertynen	Report Editor
– **JF&A Frassanito**	Graphics Support (sub contract)

Deliverables

- **Reports:**
  - **Bi-Monthly Technical Letter Progress Reports**
  - **Mid-Term Progress Report on Overall Study Effort**
  - **Summary Report on Results of NIAC Sponsored Mini RFI**
  - **Final Report Including:**
    - **Results from RASC/ICASE Workshop**
    - **Identification of Most Promising Advanced Concepts - with supporting graphics**
    - **Evaluation of RASC Enabled Science**
    - **Recommendation of Critical R&T Investments**
  - **Summary Presentation of Final Report**